A DOUBLER MAGNET-LATTICE,

WITH LONG STRAIGHT SECTIONS

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The doubler magnets have an overall, center-to-center, length of 22 feet (264 in.) which is 13 in. longer than the corresponding main-ring magnet length of 239+12=251 in. This added length is easily accommodated in the regular cell by shortening the quadrupole and the correction element space – using the relatively greater strength of superconducting multipoles. The accommodation is not so easy in the long straight sections. The squeeze on the quadrupoles is such that a one-to-one correspondence with the main-ring structure is not possible; in particular three extra quadrupole lengths are required. In the following I give a description of a satisfactory doubler long-straight section. This is the result of an extended exercise in arithmetic and I spare you the details of the process.

The conditions to be satisfied are:

a. A doubler quad has 25.7 kG/inch when the bend has 45 kG.

b. Except in the long straight, bending centers are super-imposed so that the doubler beam lies directly below the main-ring beam in the quads. In the long straight the doubler beam is parallel to and slightly outside the main-ring beam.

c. The lattice is matched at a tune of 19.4

d. The Doubler has the best match to the Main Ring for direct

beam transfer in the long straight.

e. No object intrudes into a clear space directly in line with the main-ring clear straight-section. An extra space of 12 in. just outside this clear region is allowed for the doubler warm-up box which provides the transition from 4°k to room temperature.

Slot Lengths

The concept of "slot length" is useful. The slot length of an element is the overall length including its share of the connecting structure. It is the same as center-to-center length of repetitive elements. The diagrams below give slot lengths in inches. The following are main-ring or assumed doubler values:

		magnetic	slot
Main Ring	dipole	239 in.	251 in.
	quad	84	96
	short quad	51.95	63.95
	correction	-	71
Doubler	dipole	252	264
	all quads	-	mag + 12

and the following are calculated

	magnetic	slot
Doubler correction	-	50.5
reg. quad	52.5	64.5
st. sect. quad	32.51	44.51
st. sect. quad	59.94	71.94
st. sect. quad	79.68	91.68

Description

Figure 1 shows the arrangement of a regular half cell. The center of the four-bend groups are aligned so the doubler quad slot starts 26 in. after the main-ring quad slot but terminates 5.5 in. earlier, thus the doubler quad center is 10.25 in. downstream from the main-ring quad center. Once established this quad spacing must be maintained. The lower diagram in Figure 1 shows that the medium straight section cell requires a 13 in. filler piece in order to keep this quad spacing and to match bend centers. (Resist the temptation to shove the magnets against the quad. That produces a permanent ±1/4 in. orbit distortion which is easiest corrected by - a 13 in. filler.)

Figure 2 shows the long straight section. The 10.25 in. quad shift is here reflected in a shift of the straight section center. This shift plus the temperature transition end box puts a 22¼ in. squeeze on one side of the doublet space. The other side is also squeezed as follows: Starting at the bottom we see properly aligned correction spaces and quad ends of a regular half cell. If the pre-ceeding 4-bends were aligned there would be an available slot of 32½ in. for the end quad, which is too small. It is necessary to move the 4-bend towards the straight section center (by 12.06 in., it turns out) and to move the 3-bend in the upstream end by 4/3 as much to maintain closure. As a result the doubler beam lies outside the main-ring beam in the clear straight section, by .392 in., and the doublet space is squeezed to 298.37 in. instead of 345.95 in. as in the Main Ring. This squeeze necessitates the different quad arrangement. There is a range of beta's possible with various sets of quad lengths and magnet shifts. The particular set chosen herein has the following desirable features, in order of importance:

a.   The maximum beta in the doublet is 121.08 M, slightly smaller than in the main-ring. An efficient extraction requires avoidance of high-peak betas so that the fullest aperture can be used.

b.   Direct transfer of beam from Main Ring to Doubler without matching quads is very attractive. With these parameters, the area of the doubler phase ellipse which contains the main-ring beam is less 4% larger.

c.   In the small region of this minimum mismatch, this particular set has delightfully round numbers. Note in this regard the regular quad magnetic length is 52.500 in. and one should strive to achieve this within ±.02 in,, in which case tuning quads need not be powered throughout much of the cycle.

Beam functions

This lattice has for the regular cell

$$\beta_{max} = 99.692 \text{ M}$$
$$\beta_{min} = 28.603 \text{ M}$$

phase   67.695°/full cell.

and a peak β in the long straight = 121.08 M.

Appended are tables of the usual functions for horizontal and vertical beams. The tables are unusual only in that:

a.   Old numbering, 0 - 34, is used. Odd numbers are horizontal focussing points and 7 is the medium straight.

b.   The positions are in the center of the correction space, or in other spaces where multiple entries occur. The diagrams show the location of the tabulated points.

c.   Phase advance is in degrees with multiples of 360 removed.

Chromaticity Correction

With a definite lattice design one can calculate the
requirements for chromaticity correction. Chromaticity is the
variation of betatron tune with momentum arising from the change
of quad focal power with momentum. A permanent correction of
this effect is highly desirable (as in the Booster, and all
electron machines from CEA on) not only to supress head-tail
instability, but more importantly for the freedom of rf manipu-
lation that results. The usual correction is to include a sextupole
in the bending magnets closer to the F quad and another sextupole
of opposite sign in the bends nearer the D quad.

The construction of superconducting magnets with a particular
small sextupole is just as easy as constructing them with zero
sextupole. The nuisance is that it creates two very slightly
different magnet types. At the present stage of doubler con-
struction this nuisance may seem very large but I submit that a
seperately powered set of many strong sextupoles, programmed to
follow the bending fields, with all the possibility of failure and
misadjustment, is a continuing nuisance which we would regret. In
fact we have yet to provide the Main Ring with such a system ex-
cept near injection energy where it is essential.

Let us call the dipoles nearer to an F quad (odd number) f
dipoles; and those nearer to a D quad d. In the straight section
the 3 upstream dipoles (33-34) are all f, and the 4 downstream
dipoles (1-2) are all d. A numerical computation for this lattice
gives for the permanent chromaticity correction sextupole in f
type dipoles $2.85 \times 10^{-4}/in^2$ or .0717/inch integrated over the length
in d type dipoles $-3.51 \times 10^{-4}/in^2$ or $-.0884$/inch integrated.

A positive sextupole component causes the field to increase towards the horizontal edges.

Final Remarks

The lattice herein is a good one, but it is based on the assumption that slot lengths are 12 in. longer than magnetic lengths. This is not intended as a requirement on the magnet designers. They have a most difficult problem of obtaining quality end fields without excessive peak field points and a complex mechanical problem in the connecting structure. I will be happy to repeat this arithmetic exercise as many times as is useful until a final set of quad lengths is reached.

CELL GEOMETRY

Fig 1.

REGULAR CELL

(117) — (117)

96   71   64.5   50.5   26   5.5   26   10.25

bends 4(251)   bends 4(264)

Main Ring   Doubler

MEDIUM STRAIGHT.

tabulated points

⑦   ⑦   ⑧

71   502   515   5.5   10.25   50.5   13   2(251)   2(264)   Filler   15   10.25

Main Ring   Doubler
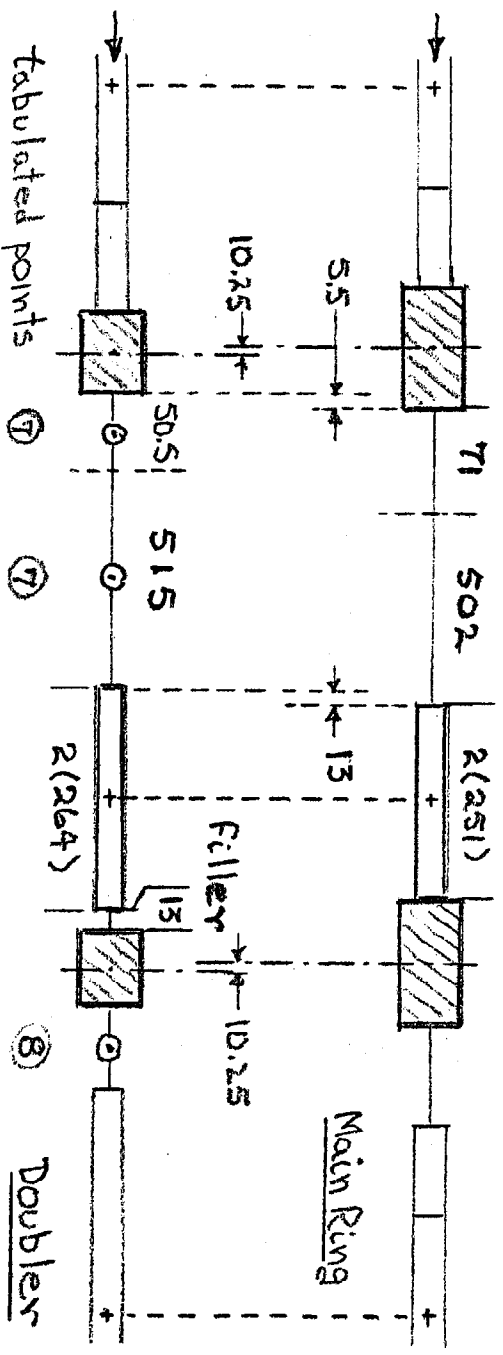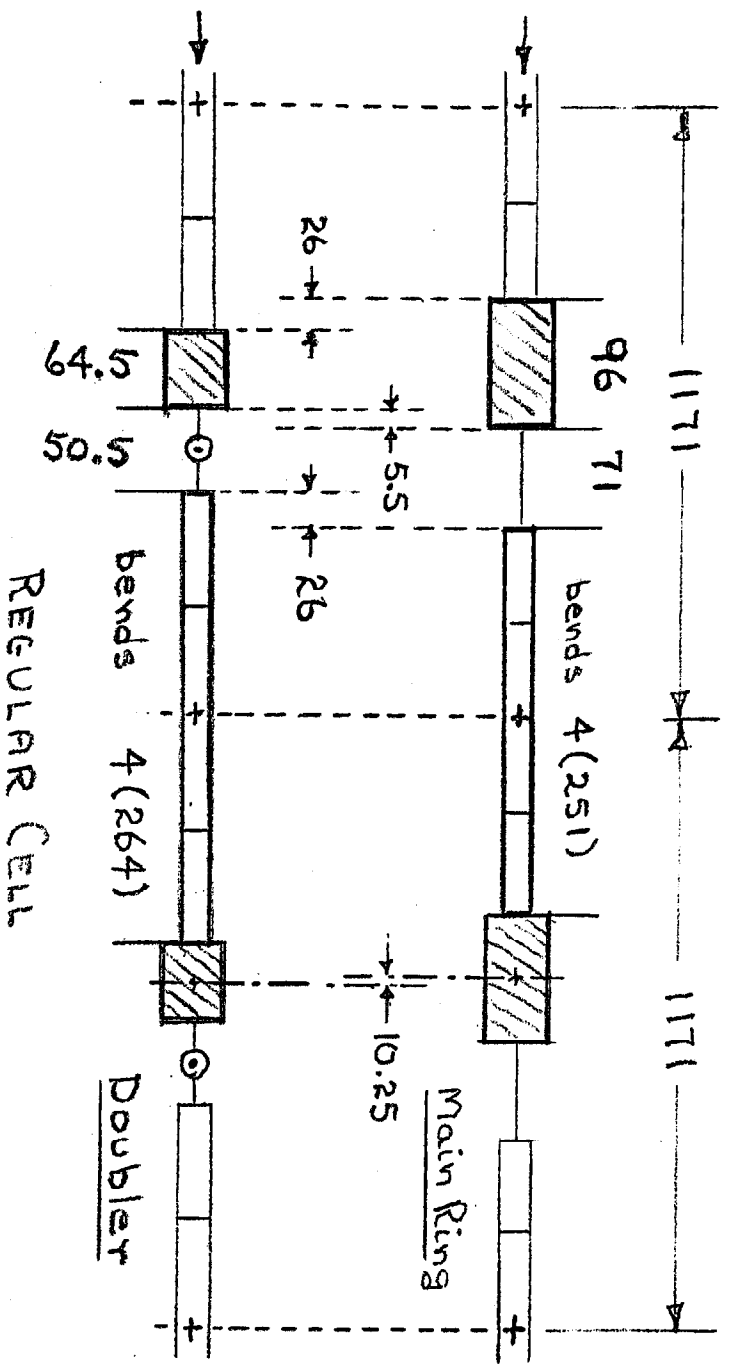
Slot lengths - inches. Effective magnetic length is
6 inches shorter on each end.

Doubler bend 264" slot, 252" mag; quad 64.5" slot, 52.5" mag.

Long St. Section Geometry.   Fig. 2.   TM-678
0428.000

Main Ring   Doubler

                                              bend cent.

short quad   26   2(264)
                                    44.51   F quad
71   33   50.5   corr.
283.05   33   293.57

                   16.08   3(264)   bends

quads   71.94   F quad
                   34   134.75
                                   91.68   D quad
                   34   12   end box

1989.35   10.25   35   2009.85

                   20.5

                             12   end box
quads   91.68   F quad
                                   154.75
                                   71.94   D quad
103.05   1   80.07

                   12.06   4(264)   bends

short quad   5.5   44.51   D quad
71   2   50.5

                                   2(264)

                                              bend cent.

"slot" lengths - inches   ↑ positions tabulated.
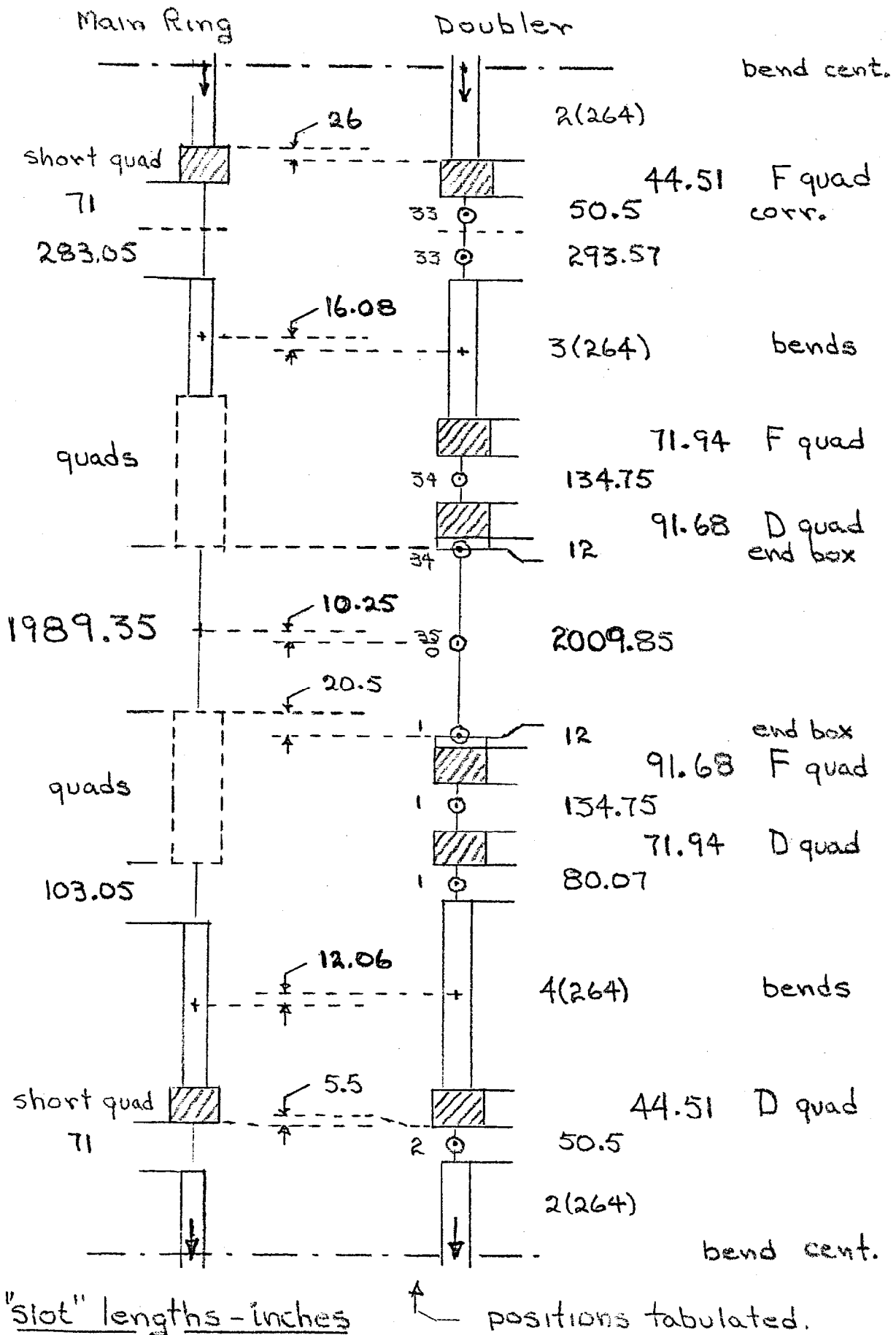
HORIZONTAL TUNE 19.4017   0 % OFF-MOMENTUM.

	DEGREES	BETA-X.	ALPHA	ETA-X.	ETA SLOPE m-rad.
0	0	70.45	-0.693	2.16	24.2
1	16	119.5	-1.289	2.78	24.2
1	18	92.49	4.924	2.42	-134.9
1	22	64.07	1.131	1.98	-44.1
2	66	29.92	-0.608	1.21	16.4
3	98	95.51	1.837	2.09	-31.5
4	134	29.92	-0.608	1.75	64.5
5	165	95.48	1.836	3.96	-55.3
6	201	29.92	-0.608	2.98	86.7
7	233	95.51	1.837	5.75	-103.2
7	238	71.49	1.508	5.01	-103.2
8	269	29.92	-0.608	3	26.4
9	301	95.49	1.837	4.06	-99.6
10	337	29.91	-0.608	1.7	-1.9
11	9	95.48	1.836	2.04	-49
12	44	29.92	-0.609	1.15	26.3
13	76	95.51	1.837	2.38	-30.2
14	112	29.92	-0.608	2.03	76
15	144	95.48	1.836	4.55	-66.7
16	180	29.91	-0.608	3.25	85.5
17	212	95.49	1.836	5.96	-113.1
18	248	29.92	-0.608	3.29	43.1
19	279	95.51	1.837	4.81	-111.9
20	315	29.92	-0.608	2.11	1.3
21	347	95.48	1.836	2.51	-64.5
22	23	29.92	-0.608	1.17	12.1
23	55	95.51	1.837	1.93	-29.8
24	91	29.92	-0.608	1.64	62
25	122	95.49	1.837	3.78	-50.8
26	158	29.91	-0.608	2.93	89.1
27	190	95.48	1.836	5.77	-101.5
28	226	29.92	-0.609	3.45	59.8
29	258	95.51	1.837	5.43	-118.9
30	294	29.92	-0.608	2.54	10.4
31	326	95.48	1.836	3.18	-81.5
32	1	29.91	-0.608	1.34	2.3
33	33	98.91	0.44	1.85	-8.9
33	35	95.3	0.388	1.81	-8.9
34	54	65.38	3.217	1.69	-64.2
34	58	48.77	-0.157	1.54	24.2
35	84	70.45	-0.693	2.16	24.2

VERTICAL TUNE-- 19.4017   0 Z OFF-MOMENTUM

	DEGREES	BETA-M.	ALPHA
0	0	70.45	0.693
1	26	48.77	0.157
1	30	65.38	-3.217
1	34	83.89	-0.112
2	53	95.49	1.837
3	88	29.91	-0.608
4	120	95.48	1.836
5	156	29.92	-0.609
6	188	95.51	1.837
7	224	29.92	-0.608
7	236	41.02	-0.937
8	256	95.48	1.836
9	292	29.91	-0.608
10	323	95.49	1.836
11	359	29.92	-0.608
12	31	95.51	1.837
13	67	29.92	-0.608
14	99	95.48	1.636
15	135	29.92	-0.608
16	166	95.51	1.837
17	202	29.92	-0.608
18	234	95.49	1.837
19	270	29.91	-0.608
20	302	95.48	1.836
21	338	29.92	-0.609
22	10	95.51	1.837
23	45	29.92	-0.608
24	77	95.48	1.836
25	113	29.91	-0.608
26	145	95.5	1.836
27	181	29.92	-0.608
28	213	95.51	1.837
29	249	29.92	-0.608
30	280	95.48	1.836
31	316	29.92	-0.608
32	348	95.51	1.837
33	23	28.87	-0.163
33	31	30.97	-0.319
34	66	92.49	-4.924
34	68	119.5	1.229
35	84	70.45	0.693